The PTP Model Proposed in the NPRM in MM Docket No. 98-93

Field Strength Prediction in Irregular Terrain

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This report describes a prediction technique for the calculation of radio field strength in irregular terrain situations. The concept of an "equivalent rounded obstacle" is introduced to account for radio propagation losses over various possible irregular terrain shapes, including shapes which cannot easily be described. The technique replaces an arbitrary terrain profile with an equivalent rounded obstacle for which a value of path loss can be calculated using appropriate formulas.

The technique was derived for the purpose of translating our experience in examining many hundreds of situations into a procedure which can be automated to streamline certain regulatory procedures. We believe that the path loss values calculated will be reasonably accurate when the technique is applied to profiles of real terrain. This is being tested by comparison with propagation measurements.

This technique for estimating field strength, in combination with some additional rules for determining contour distances, is proposed as a "point-to-point" (PTP) model in a recent FCC Notice of Proposed Rulemaking. The model would be used to predict FM radio service and interference in certain limited instances. Currently, the FCC is requesting public comment on the model, and comparisons with propagation measurements can be viewed on the FCC Worldwide Web site [ftp://www.fcc.gov/pub/Bureaus/Engineering_Technology/Databases/mmb/fm/model].

1. DIFFRACTION LOSS CALCULATIONS

Diffraction loss for an ideal knife-edge obstruction can be calculated from the famous Fresnel integral. This integral originated in studies of optics by Augustin-Jean Fresnel in the early 19th century. In application to radio propagation, formulas based on this integral have frequently provided close approximations to the diffraction effects of isolated mountain ridges.

In most situations however, the terrain does not at all resemble a simple knife-edge, and to represent obstructions in this simple way would underestimate the diffraction loss. Solutions for the diffraction loss over an isolated "rounded" obstacle have been given by Rice [1], Neugebauer and Bachynski [2][3], Wait and Conda [4]. In addition, Dougherty and Maloney [5] provide a readily evaluated formula for computing the diffraction loss over a rounded obstacle in terms of quantities υ and ρ, where υ is the dimensionless parameter of the Fresnel-Kirchhoff diffraction formula and ρ is a mathematically convenient dimensionless index of curvature for the crest radius of the rounded obstacle. Diffraction loss is greater for broader obstacles of this type, increasing as the radius of curvature and ρ become larger.

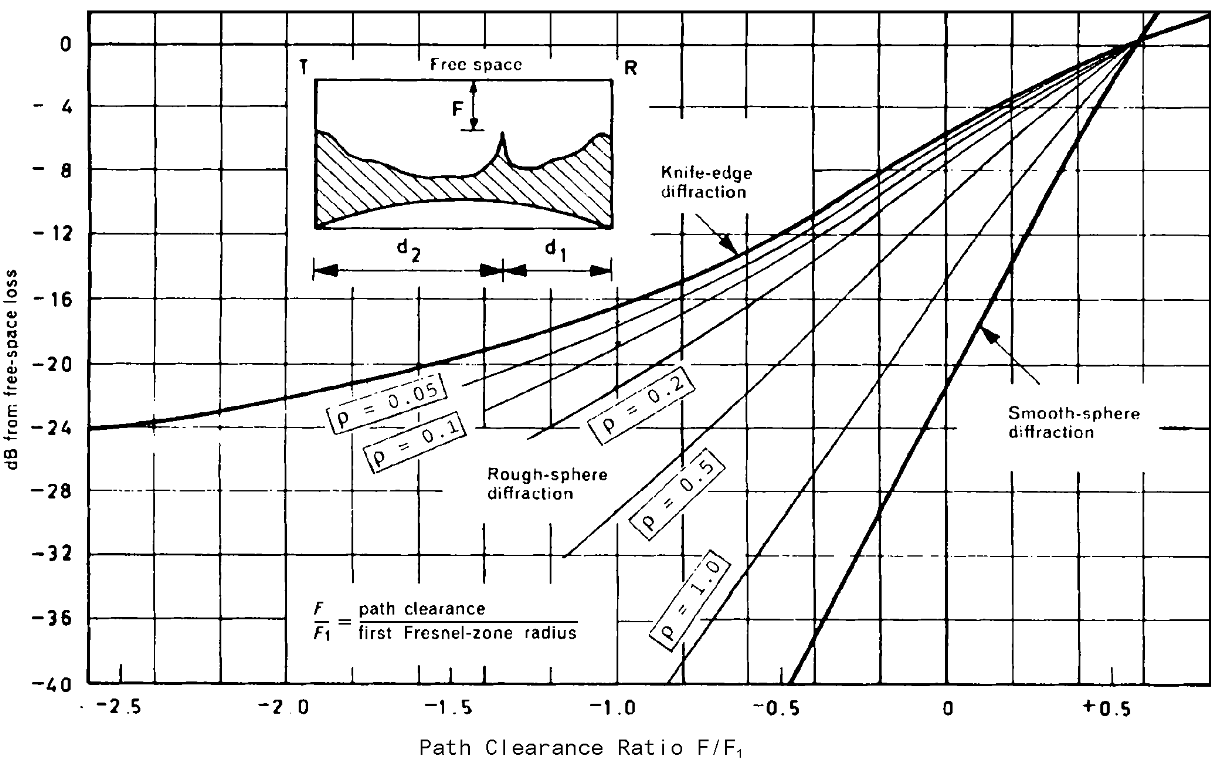
The diffraction loss in every situation is somewhat less than would be calculated by replacing irregular terrain with a smooth spherical earth, the ultimate rounded obstacle. Methods of calculating the diffraction loss over a smooth spherical earth have been given by Burrows and Gray [6] and by Norton [7]. (These methods are difficult to apply, however, and here we resort to a formula obtained by fitting a curve in a CCIR graph as discussed in the next section.)

Diffraction losses due to multiple knife-edges also lie somewhere in the range between those for single knife-edge and smooth-earth terrain models. Deygout [8] provides easily implemented procedures for calculation when the terrain can be represented this way. The technique described in this report does not involve multiple knife-edge considerations. However, we expect the equivalent rounded obstacle approach to give reasonably accurate results even in situations better described by multiple knife-edges. This is being tested.

2. GRAPH OF DIFFRACTION LOSS

CCIR [9] provides a graphical representation of knife-edge and smooth-sphere diffraction loss relative to that of free-space in terms of the ratio of path clearance to the radius of the first Fresnel zone. The figure below is the CCIR graph with the addition of the Dougherty-Maloney diffraction adjustments for rounded obstacles. Note: the ratio of path clearance to first Fresnel radius, F/F_1 in the figure, equals the Dougherty-Maloney parameter υ divided by the square root of 2.

It is found in the figure that the diffraction loss for ρ=1.0 is 0.6 of the way downward between the losses for knife-edge and smooth-sphere for all path clearance ratios, that is, for all values of F/F_1. A similar proportion holds for the other values ρ, and hence we can characterize rounded obstacles by this proportion just as well as by the values of the Dougherty-Maloney parameter ρ. We denote this proportion by the symbol R, and call it the equivalent roundness factor. This graphical interpretation of the figure is the basis of the formulas used in the equivalent rounded obstacle model. Knife-edge diffraction corresponds to R = 0.0; smooth-earth to R = 1.0.



The bounding curves in the figure, that is, those for knife-edge and smooth earth, can be described by approximate formulas. Letting $x = F/F_1$, the diffraction loss (relative to free-space) for a smooth-sphere diffraction is approximately

$$\text{Smooth-sphere Loss} = -38.68x + 21.66 \text{ dB},$$

and for a knife-edge

$$\text{Knife-edge Loss} = 1.377x^2 - 11.31x + 6.0 \text{ dB} \quad \text{for } x > -0.5$$

$$= -50.4/(1.6 - x) + 36.0 \text{ dB for } x < -.5.$$

Now when both F/F_1 and R are given, path loss by the equivalent roundness model is be found by

$$\text{Path Loss} = \text{Knife-edge Loss} + R\,(\text{Smooth-sphere Loss} - \text{Knife-edge Loss}).$$

Section 3 describes how F/F_1 is determined; section 4 discusses the estimation of the equivalent roundness factor, R.

3. PATH CLEARANCE RATIO, F/F_1

A major factor in determining diffraction loss is the clearance ratio, F/F_1. The inset diagram in the CCIR figure indicates how this quantity is defined. Consider a specific point-to-point path and the terrain elevations at all intermediate points from the transmitter. The height of the transmitter is presumed to be given, the receiver height is assumed to be 9.1 meters above the surface of the earth in FM radio service applications, and these heights determine a line of sight which may pass through or over obstacles. At a specific point along the path, the clearance F is the difference in height between the line of sight and the terrain elevation. At that same point we calculate the radius F_1 of the first Fresnel zone and form the ratio F/F_1. The primary obstacle is at the point where this ratio is a minimum.

The first Fresnel radius in meters is given by

$$F_1 = 548\sqrt{d_1 d_2 /(f\,d)}$$

where d_1 = distance to the near end of path in km, d_2 = distance to the far end of path in km, $d = d_1+d_2$ = total path length in km, and f = frequency in MHz.

4. TERRAIN VARIATION AND EQUIVALENT ROUNDNESS FACTOR

An equivalent roundness factor must be defined to complete the model. We can imagine a statistical project in which propagation measurements are to be arranged in groups with each group having approximately the same loss and the same path clearance ratio. In this project we would then try to identify commonalities in the various groups of terrain profiles. In place of this project, which would probably be very costly, we make a guess that terrain variation (ΔH in what follows) occurring near the primary obstacle is the major commonality that would be found. This amounts to assuming that equivalent roundness is highly correlated with the terrain variation parameter. We also establish an *a priori* relationship between R and ΔH. This relationship is

$$R = 75 / (\Delta H + 75).$$

ΔH is defined as follows: A straight-line least-squares fit is made to the terrain elevations within 10 km of the primary obstacle. The variance of these terrain elevations relative to the straight-line fit is then calculated, and ΔH is set equal to 90 percent of the standard deviation.

Assuming that terrain variations tend to be somewhat similar within a relatively small area, ΔH will give an indication of the type of primary obstacle (smooth rolling hill, rugged mountain, etc.). Note the following:

- For $\Delta H = 0$ m, there is no terrain variation. Terrain is assumed to be smooth and the primary obstacle is that of a smooth earth.

- $\Delta H = 50$ m corresponds to a hill about 55 meters high. This indicates rolling terrain in which hilltops usually have a fairly large radius of curvature. Limited field strength measurements indicate a diffraction loss equivalent to that for a rounded obstacle with an index of curvature, ρ, of 1.0 (0.6 of the diffraction loss from knife-edge to smooth-earth).

- $\Delta H = 200$ m indicates a large mountain where the peak is fairly sharp. A rounded obstacle with an index of curvature, ρ, of 0.5 (0.25 of the diffraction loss from knife-edge to smooth-earth) provides a close estimate.

This formulation is based on experience in examining many hundreds of real situations. For example, we have observed that when there are secondary obstacles, they tend to be sharper and therefore individually cause less diffraction loss. The total diffraction loss will include additional but smaller components. Thus for the same ΔH, the effects of sharper but more numerous obstacles negate each other.

The technique described in this report must produce a path loss reasonably close to the prediction of multiple knife-edge methods wherever the latter are appropriate. Obviously the technique must also agree reasonably well with propagation measurements. These matters are being investigated.

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